ADDITIVE SUMMATION FOLLOWING INTRADIMENSIONAL DISCRIMINATION TRAINING

ROBERT J. HAMM[1] AND JAMES C. MATTSON

VIRGINIA COMMONWEALTH UNIVERSITY

Rats were exposed to intradimensional composite stimuli presented on the response lever that varied in both light intensity and flicker rate. For all subjects, pressing the lever was reinforced when it was illuminated at a high intensity and flickered at a low rate (I + f) or when it was illuminated at a low intensity and flickered at a high rate (i + F). For half the subjects, lever responding was not reinforced when it was illuminated at a low intensity and flickering at a low rate (i + f). For the remaining subjects, lever presses were not reinforced when the lever was illuminated at a high intensity and flickered at a high rate (I + F). When the composite stimulus composed of the light intensity and flicker rates that had been associated only with reinforced responding was displayed (I + F for half the subjects and i + f for the remaining subjects), it controlled the highest response rate of all stimuli (additive summation). The results demonstrated that similar attentional processes control intra- and interdimensional composite-stimulus discriminations in a manner consistent with Weiss' (1972) analysis of summation.

Key words: summation, stimulus compounding, successive discrimination, multiple schedule, lever press, rats

---

Additive response summation refers to the increase in response rate observed when stimuli that have been separately conditioned to control the same response are simultaneously presented. A frequently used method of investigating the summation phenomenon is to use a multiple schedule of reinforcement. For example, Weiss (1964) reinforced bar pressing by rats under a multiple variable-interval 30-sec, variable-interval 75-sec, extinction schedule (mult VI 30-sec VI 75-sec EXT), with light (or more precisely, light plus no-tone, abbreviated as L+T̄) and tone (no-light plus tone, L̄+T) being associated with the respective VI schedule components and no-light plus no-tone (L̄+T̄) being associated with the extinction component. After stable differential responding was established, a test for response summation was conducted by presenting the two VI-associated stimuli (i.e., L+T̄ and L̄+T) simultaneously. The results showed that this composite test stimulus (L+T) controlled a higher response rate than either of the VI-associated stimuli.

Weiss' (1972) analysis of the summation phenomena assumes that the subjects discriminate the presence and absence states of the light and tone stimulus elements that comprise the composite stimuli, and that the behavior controlled by the composite stimulus is a "mix" of the response rates controlled by each element. Since L+T is a composite stimulus constructed of stimulus elements that have been either discriminative for a response-rate increase or signalled an increase in reinforcement frequency, it should control the highest response rate of all composite stimuli. To illustrate, compare L+T, the summation test stimulus, to either L+T̄ or L̄+T, the two VI-correlated stimuli in Weiss' (1964) experiment. The composite stimulus L+T was composed of both a light element and tone element that had been only associated with reinforced responding and were discriminative for a response-rate increase. The composite stimuli L+T̄ and L̄+T both contain only one element that has been associated with reinforced responding or were discriminative for a response-rate increase, since L̄ and T̄ were elements comprising L̄+T̄, the composite stimulus associated with nonreinforced responding.

Although additive summation is a well-established behavioral phenomena, it has been investigated only following discrimination training based on the presence-absence of particular physical stimulus dimensions (in most

cases the presence-absence of light and tone).
Mackintosh (1974, p. 507) classified discrimina-
tion training that differentially correlates re-
inforcement with the presence or absence of
particular stimulus dimensions as interdimen-
sional discrimination training. Interdimen-
sional discrimination training is contrasted
with *intra*dimensional discrimination training
in which two values on a particular physical
stimulus dimension (*e.g.*, high-intensity light
and low-intensity light) are correlated with
differential reinforcement. Employing the in-
ter- and intradimensional terminology, the
summation training procedure is essentially
an interdimensional discrimination training
procedure concurrently conducted on the light
and tone stimulus dimensions. The purpose of
the present investigation was to determine
whether similar attentional processes are in-
volved in producing summation when using
an intradimensional discrimination training
procedure as when using an interdimensional
training procedure. More specifically, high and
low light intensities and high and low flicker
rates were used as the intradimensional stimu-
lus substitutes for interdimensional discrimi-
nations of previous summation studies.

METHOD

Subjects

Four naive male hooded rats, 90 to 120 days
old, were placed 10 days before the start of the
experiment on a 23-hr food-deprivation regi-
men that maintained them at 80% of their
free-feeding weights.

Apparatus

A BRS/LVE Moducage was used. The cham-
ber measured 22.3 cm high, 24.5 cm long, and
24.2 cm wide. The side walls and ceiling were
clear plastic; the front and rear walls were
white painted aluminum. The front wall of
the chamber had the following configuration:
a response lever centered on the midline of
the wall and 4.5 cm above the grid floor, a
food-pellet cup located 4 cm from the right
wall and 1 cm above the floor.

The response lever was made of clear plastic
and was 2 cm wide and 3 cm long. A 0.2-cm
diameter hole was drilled into the center of
the response lever in order to insert a light
bulb (#434, Grain of Wheat Bulb). The sur-
face of the plastic response lever was lightly
sanded in order to diffuse the light from the

bulb evenly over the entire response lever. The
response lever was illuminated with one of
two intensities. The high-intensity light was
produced by 24 V dc with a 100-ohm resistor
in series with the bulb. The low-intensity
light was produced by 24 V dc with a 380-ohm
resistor in series with the bulb. The bulb
within the response lever also allowed illum-
ination of the response lever at two flicker
rates. The flicker rates were 1 and 10 flashes
per second, each flash of 40-msec duration.
The light intensities and flicker rates were in-
dependently controlled (*i.e.*, either light in-
tensity could be presented at either flicker
rate and *vice-versa*). A force of 0.12 N was
necessary to operate the lever.

Solid-state programming equipment was lo-
cated in an adjacent room and controlled stim-
ulus events and response recording.

Procedure

Preliminary training. Rats were trained to
approach and eat 45-mg food pellets from the
food cup when the feeder was operated. Sub-
jects were then trained to press the response
lever. During this phase, the lever was not il-
luminated. The schedule of reinforcement was
gradually changed over sessions to a VI 60-sec
schedule. Five 50-min sessions were conducted
with lever presses being reinforced under a
VI 60-sec schedule to produce a fairly stable
response rate. See Table 1 for a summary of
this phase of the procedure.

Component discrimination training. During
this phase, responses were reinforced under a
multiple schedule. When the lever was il-
luminated at a high intensity (S+, abbreviated
as I), lever presses were reinforced on a VI 30-
sec schedule for R33 and R2. When the lever
was illuminated at a low intensity (S−, ab-
breviated as i), presses were not reinforced.
Twenty seconds without a lever press ($\overline{R} > 20$
sec) in S− resulted in the presentation of the
VI-correlated stimulus (I). This is a modified
multiple schedule *mult* VI 30-sec EXT* ($\overline{R} >$
20 sec). The VI component was terminated
after 2 min to ensure that each VI-associated
stimulus was presented for an equal duration
during each session. For R11 and R5, the
stimuli correlated with the VI and EXT* com-
ponents of the multiple schedule were reversed
in order to counterbalance stimulus intensity
between subjects. A session consisted of 12, 2-
min presentations of the stimulus associated

Phase	Schedule	Stimulus	· Number of Sessions
Preliminary training	FR 1	Bar not illuminated	2
	VI 15-sec	Bar not illuminated	1
	VI 30-sec	Bar not illuminated	2
	VI 60-sec	Bar not illuminated	5
Component discrimination training	*mult* VI 30-sec EXT*	Intensity	5
	mult VI 90-sec EXT*	Intensity	10
	mult VI 30-sec EXT*	Flicker rate	5
	mult VI 90-sec EXT*	Flicker rate	10
Composite discrimination training	*mult* VI 30-sec EXT*	Intensity and flicker rate	36
Test for summation	*mult* VI 30-sec EXT*	Intensity and flicker rate	15
	mult VI 30-sec EXT	Intensity and flicker rate	9

with the VI schedule and 12 presentations of the stimulus associated with the EXT* schedule. The VI and EXT* schedules alternated. Five sessions were conducted with the *mult* VI 30-sec EXT* correlated stimuli. The VI component of the multiple schedule was then changed to a VI 90-sec schedule for 10 additional sessions in order to reduce both the number of the reinforcements delivered in a session and the response rate during S+.

During the next 15 sessions, the response lever was illuminated at an intermediate intensity (24 V dc through 200 ohms) and flickered at a high (10 flashes per second, abbreviated as F) or low (one flash per second, abbreviated as f). For R33 and R2, responses on the lever when it was flashing at a high rate were reinforced under a VI 30-sec schedule for five sessions. After these five sessions, the schedule was changed to VI 90-sec for the remaining 10 sessions to reduce both the number of reinforcements delivered in a session and response rates during S+. The EXT* schedule was in effect when the response lever was flashing at a low rate. For R11 and R5, the stimuli correlated the VI and EXT* schedules were reversed. As before, a session consisted of 12, 2-min presentations of the VI-associated stimulus and 12 presentations of the EXT*-correlated stimulus. (See Table 1.)

Composite discrimination training. During this phase, the light-intensity and flicker-rate stimulus dimensions were simultaneously presented on the response lever. For all rats, two composite stimuli were associated with reinforced responding. A high-intensity light at a low flicker rate (I+f) and a low-intensity light at a high flicker rate (i+F) were separately correlated with a VI 30-sec schedule of reinforcement. For R33 and R2, an EXT* schedule was in effect when the lever was illuminated at a low light intensity and flickered at a low rate (i+f). To control for any stimulus intensity effects, for R11 and R5 the EXT*-associated stimulus was the lever illuminated with a high-intensity light at a high flicker rate (I+F). A session consisted of six, 2-min presentations of each VI-associated stimulus and 12 presentations of the EXT*-correlated stimulus. The VI and EXT* schedules alternated and the order of VI-associated stimuli was changed irregularly between sessions. This phase of training was followed for 36 sessions in order that response rates during the various stimuli showed no systematic increasing or decreasing trend over the last 10 sessions.

Test for summation. Testing involved compounding the light intensity and flicker rate that had not been previously associated with the EXT* schedule. For R33 and R2, the appropriate summation test stimulus was a high-intensity light at a high flicker rate (I+F). For R11 and R5, the summation test stimulus was a low light intensity at a low flicker rate (i+f). The test stimulus was introduced into the *mult* VI 30-sec EXT* schedule as the third stimulus (the others being I+f and i+F) associated with the VI 30-sec schedule. A possible criticism of this testing procedure is that if there were a tendency for the initial presentations of the summation test stimulus to increase response rate, reinforcing that rate might sustain it, independent of the summation effect. This potential criticism can be answered in two ways:

(1) if the schedule did maintain the increased rate caused by introduction of the summation test stimulus, the testing procedure would be simply maintaining the initial summation effect. (2) Wolf (1963) has shown that an initial summation effect was not maintained by reinforcing responding during the summation test stimulus.

A test session consisted of four separate 2-min presentations each of the three VI-correlated composite stimuli and 12 presentations of the EXT*-associated stimulus. The VI and EXT* schedules alternated. Testing continued for 15 sessions with a *mult* VI 30-sec EXT* schedule. The schedule was then changed to a *mult* VI 30-sec EXT schedule without the $\bar{R} > 20$ sec dependency for an additional nine sessions. The change in schedule was accomplished by lengthening the duration of the EXT-associated stimulus to a constant 2 min. Responses during S^- no longer postponed presentation of the S^+. After the 2-min presentation of the EXT-associated stimulus, a VI-associated stimulus was presented. There were four, 2-min presentations of the EXT-correlated stimulus within each 48-min session. Again, the order of the VI-associated stimuli was irregularly changed between sessions. See Table 1 for a summary of this procedure.

RESULTS

Figure 1 shows the mean response rates during the composite stimuli calculated in blocks of three sessions. The first two blocks of sessions represent the response rates during the last six sessions of composite discrimination training before introduction of the summation test stimulus. At this point, after 36 sessions on the *mult* VI 30-sec EXT* schedule, none of the subjects showed evidence of differential responding to the stimuli associated with VI and EXT* schedules. During the first phase of summation testing (Blocks 3 to 7), the summation test stimulus was introduced as another stimulus associated with a VI 30-sec schedule of the multiple schedule. During these blocks of sessions, the summation test stimulus controlled the highest average response rate for all subjects over all blocks of sessions. During these blocks, R33 emitted 41% of its VI-associated responses during the summation test stimulus. Subjects R2, R11, and R5 emitted 42, 43, and 41%, respectively, of their VI-reinforced responses during the

test stimulus. Within the 15 sessions that comprise Blocks 3 to 7, the summation test stimulus controlled the highest response rate on 12 of the sessions for R33. For R2, R11, and R5, the summation test stimulus controlled the highest rate on 14, 11, and 13 of the 15 sessions, respectively.

On Blocks 8 to 10 the schedule was changed to a *mult* VI 30-sec EXT schedule. The change in schedule produced an increase in response rate to the VI-associated stimuli for all subjects. For R33, the increase was transient and decreased over blocks of sessions. The change in schedule also improved the difference in response rates controlled by the stimuli correlated with the VI and EXT schedules. Again, during this second summation testing phase, the test stimulus controlled the highest response rate of all stimuli for all subjects across all blocks of sessions. The respective percentages of VI-associated responses emitted during the test stimulus were 38, 39, 39, and 38 for Subjects R33, R2, R11, and R5. A within-block analysis of the response rates controlled by the summation test stimulus revealed that for R33, R2, R11, and R5, additive summation was observed on 6, 7, 8, and 6 respectively, of the nine sessions that comprised Blocks 8 to 10.

DISCUSSION

Additive response summation was reliably observed in all subjects with both multiple schedules of reinforcement. The magnitude of the summation effect varied between 38 and 43% of test-session responding. This magnitude of additive summation was not large for several reasons. First, the stimuli used in this investigation varied intramodally, since the composite stimuli varied only on visual stimulus dimensions (*i.e.*, light intensity and flicker rate). The typical experiment investigating summation has used light and tone composite stimuli, which varied intermodally (*i.e.*, on both visual and auditory stimulus dimensions). In one of the few summation experiments that used intramodal stimuli, Wolf (1963) separately associated one of three spatially separated lights (*i.e.*, $L_1 + \bar{L}_2 + \bar{L}_3$, $\bar{L}_1 + L_2 + \bar{L}_3$, $\bar{L}_1 + \bar{L}_2 + L_3$) with the VI component of a *mult* VI EXT schedule. The absence of the three lights ($\bar{L}_1 + \bar{L}_2 + \bar{L}_3$) was associated with the EXT component. When the summation test stimulus, all three lights on simultaneously ($L_1 + L_2 + L_3$), was introduced as
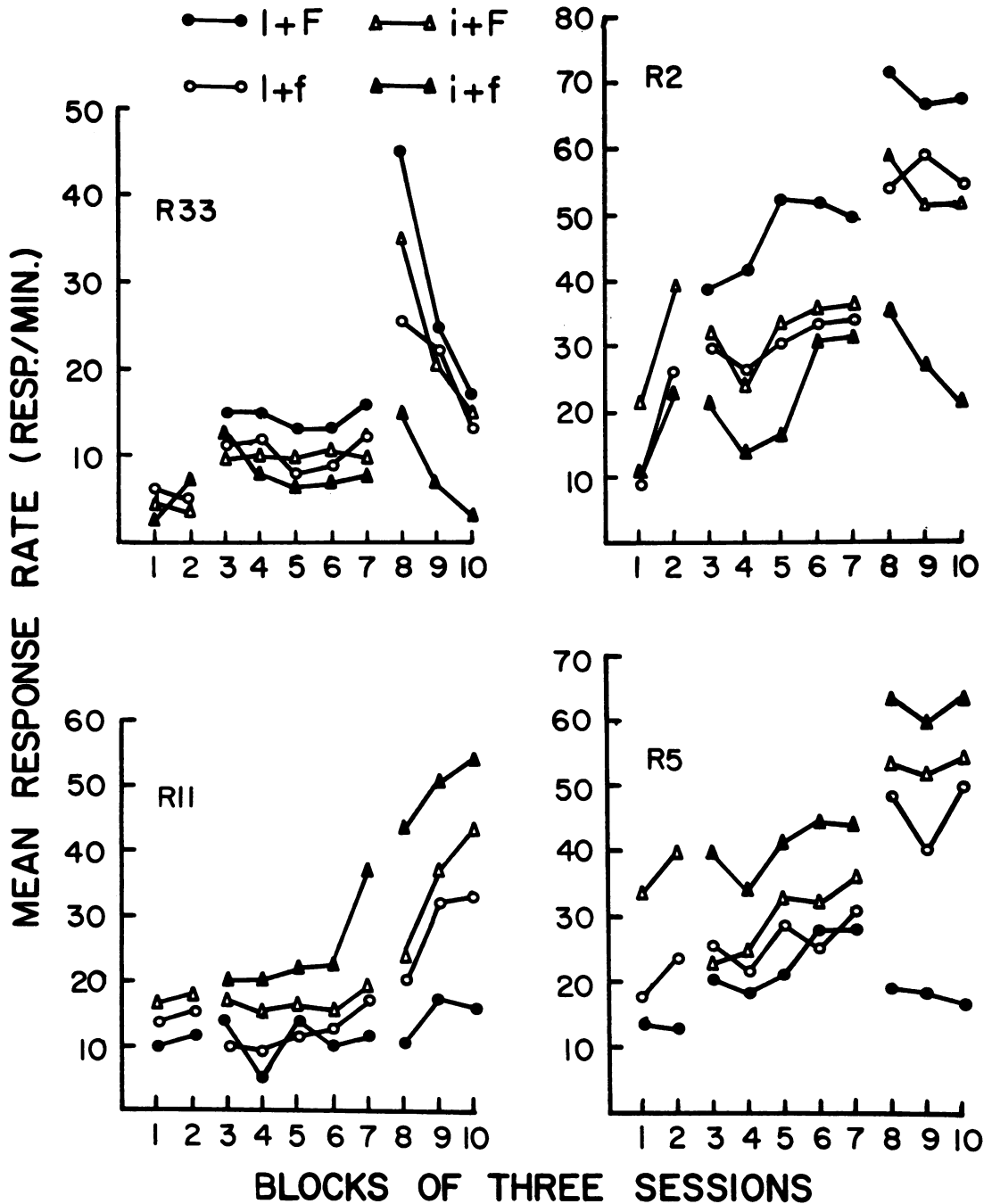
Fig. 1. Mean response rates during the composite stimuli over blocks of three sessions. Session Blocks 1 and 2 represent terminal response rates during the composite stimuli before the summation test stimulus was introduced. During Blocks 3 to 6, a *mult* VI 30-sec EXT* schedule was in effect. Under this schedule, responses were not reinforced during the EXT-associated stimulus and 20 sec had to elapse without a response before a VI-associated stimulus was presented. During Blocks 8 to 10, responding was reinforced on a *mult* VI 30-sec EXT schedule without the $\overline{R} > 20$-sec dependency.

the fourth stimulus correlated with the VI component, additive response summation was initially observed, but it decreased with continued testing. In another experiment, Miller (1971) separately associated two spatially separated lights or a tone as signals for reinforced responding. The summation test involved simultaneously turning on both lights ($L_1 + L_2$, intramodal test stimulus) or one light and the tone (L+T, intermodal test stimulus). Both the inter- and intramodal test stimuli produced additive summation, but the magnitude of the summation effect was smaller with the intramodal test stimulus.

A second reason for the small magnitude of the summation effect was the method of testing. As mentioned previously, the test for summation was not conducted during extinction. Wolf (1963) also tested for summation by introducing the summation test stimulus as another reinforcement-associated stimulus, and found that summation effect disappeared with continued testing. Thus, it was expected that composite stimuli and the method of testing used in this investigation would not produce a large additive summation effect.

Although the magnitude of the summation was small, additive summation was observed following intradimensional discrimination training. Thus, the present results demonstrate that similar attentional processes control summation in inter- and intradimensional discriminations. The results also support the generality of Weiss' (1972) analysis of summation. In his model, Weiss proposed two factors as being critical in determining the occurrence of summation. According to the model, the summation test stimulus controls the highest response rate, since it is the only composite stimulus that is exclusively composed of elements that were either (1) discriminative for a response-rate increase or (2) signals an increase in reinforcement frequency. In a number of experiments, Weiss has attempted to separate these two factors. For example, Weiss (Weiss, 1972, Weiss and Van Ost, 1974) delivered reinforcement as frequently in L+$\overline{T}$ and $\overline{L}$+T for responding as in $\overline{L}$+$\overline{T}$ for *not* responding (*i.e.*, a *mult* VI DRO schedule). Under this procedure, response rates increased during L+$\overline{T}$ and $\overline{L}$+T, but decreased during $\overline{L}$+$\overline{T}$ when reinforcement was delivered equally frequently during each stimulus. The summation test stimulus,

L+T, was therefore composed of elements that were discriminative for a response-rate increase but were not associated with an increase in reinforcement frequency relative to $\overline{L}$+$\overline{T}$. Under these conditions, L+T still controlled the highest response rate. Thus, it appears that associating the stimuli with different response rates is sufficient to produce summation.

Although not originally designed to do so, the present experiment provides suggestive data concerning the role of reinforcement frequency in determining summation. With a *mult* VI 30-sec EXT schedule in effect, the stimulus elements were associated with different reinforcement frequencies, but the response-rate data (Figure 1, Blocks 3 to 7) show that the VI- and EXT-correlated stimuli controlled very similar response rates. The summation test stimulus was, therefore, a composite stimulus composed of elements that signalled an increase in reinforcement frequency, but did not reliably control an increase in response rate. The observation of additive summation under these conditions suggest that associating the stimuli with different reinforcement frequencies is also sufficient to produce summation. Thus, the differential response rate and reinforcement frequency factors proposed by Weiss (1972) as critical in the development of composite-stimulus control each seem to be sufficient to produce summation.

REFERENCES

Mackintosh, N. J. *The psychology of animal learning.* London: Academic Press, 1974.

Miller, L. Compounding of discriminative stimuli from the same and different sensory modalities. *Journal of the Experimental Analysis of Behavior,* 1971, **16**, 337-342.

Weiss, S. J. Summation of response strengths instrumentally conditioned to stimuli in different sensory modalities. *Journal of Experimental Psychology,* 1964, **68**, 151-155.

Weiss, S. J. Stimulus compounding in free-operant and classical conditioning: a review and analysis. *Psychological Bulletin,* 1972, **78**, 189-208.

Weiss, S. J. and Van Ost, A. L. Response discrimination and reinforcement factors in stimulus control of performance on multiple and chained schedules of reinforcement. *Learning and Motivation,* 1974, **5**, 459-472.

Wolf, M. M. Some effects of combined S^Ds. *Journal of the Experimental Analysis of Behavior,* 1963, **6**, 343-347.